United States Department of Agriculture

NORTHEASTERN FOREST EXPERIMENT STATION

FOREST SERVICE

Forest Survey Note No. 1
May 15, 1946

614 Bankers Securities Building
Philadelphia 7, Penna.

# USE OF THE PARALLAX WEDGE IN MEASURING TREE HEIGHTS ON VERTICAL AERIAL PHOTOGRAPHS

By Earl J. Rogers

During the past few years aerial photographs have been used increasingly in forest survey. Foresters are learning that various classes of timber may be identified on aerial photographs in far less time and at less cost than is required by ground methods alone. One method of classification involves the estimation of tree height, based on measurements on tree images on the photographs.

A new device useful in estimating heights from vertical aerial photographs was recently introduced by Spurr[1/]. This device, called a parallax wedge, is inexpensive, simple in design, highly flexible, relatively accurate and fairly easy to master.

In the spring of 1945 this instrument was demonstrated to members of the Forest Service who later used it in the aerial photo interpretation of the forest situation on some 50 million acres of forest lands in the northeastern part of the United States. During the course of the survey the author used the parallax wedge under a wide variety of conditions, such as photo scales from 1:10,000 to 1:48,000, with photos taken during all seasons of the year and by several types of cameras. Further, this survey provided an excellent proving ground of diversified forest conditions, such as exist in complex northern hardwood, oak, white pine, and spruce-fir forests. Excellent opportunities were also presented to train men in the use of the parallax wedge and to observe their progress.

Spurr has described this instrument and made suggestions to help the observer in its use. However, some problems not fully discussed by Spurr were encountered in the use of the wedge. It is hoped that the following discussion will be of further aid to the users of parallax wedges. Although the procedure for obtaining estimates of tree heights through its use may appear complex upon first reading, actually the steps are relatively

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1/ Spurr, Stephen H., Parallax Wedge Measuring Devices, Photogrammetric Engineering, Vol. XI, No. 2

simple ones. After a little practice, one should be able to make tree-height estimates in a few minutes time.

## Suggestions on the Use of Parallax Wedges

A parallax wedge consists of two converging straight lines or rows of dots reproduced on a transparent material such as celluloid or glass. It is so calibrated that the amount of convergence can be measured (fig. 1). In use, the wedge is laid upon a pair of aerial photographs which, when viewed under a stereoscope, give an ocular impression of a three-dimensional model of the terrain, the forest cover and culture.

## Orientation of Stereoscopic Pairs of Aerial Photographs and Stereoscope

The aerial photographs should be oriented as outlined by Sanders2/ with several modifications necessitated by the use of the wedge itself.

Each photograph of a stereoscopic pair usually contains 60% of the images shown in the other. One photograph, in other words, will overlap the other by 60%. The two photographs should be separated so that the overlapped portions are adjacent. Photographs so oriented will furnish the desired stereoscopic effect. The photographs can now be considered as left and right hand photos.

Each photograph has marks commonly called fiducial marks. They are readily distinguished, either being at the center of the sides or at the corners of the photographs. The intersection of two lines connecting opposite marks locates the optical center or principal point of the photograph (fig. 1). Actually, a line need not be drawn across the entire photo but only across a short section near the center.

Since each photo of a stereoscopic pair covers approximately 60% of the other photo, the images at each principal point appear respectively on the other. With care the image corresponding to the principal point on one photo can be marked on the adjacent picture, and is called the conjugate principal point.

The right and left hand photos should now be placed in their proper position so oriented that a straight line will pass through the two principal points and the two conjugate principal points. When the photos are properly aligned in relation to each other, it is necessary to separate the photos the proper distance.

The separation desired is equal to the distance between the divergent lines in the middle portion of the wedge. If, for example, this distance on the

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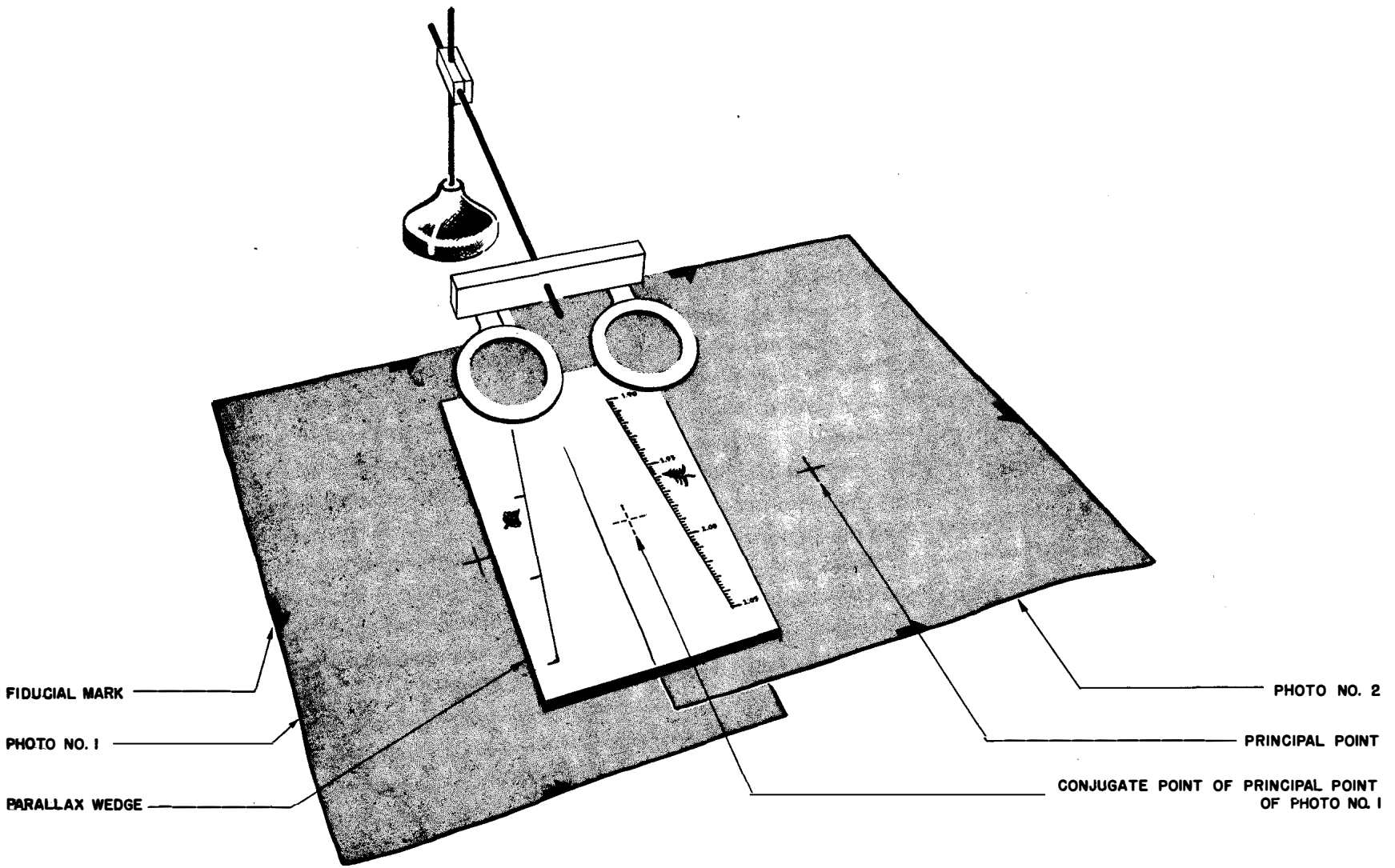
2/ Sanders, Revere G. Orient Your Stereoscope Correctly. Photogrammetric Engineering, Vol. VIII, No. 2 1942

Figure I. - ORIENTATION OF THE PARALLAX WEDGE



parallax wedge varies from 1.8" to 2.2" then the separation of photos should be about 2.0"

Not all stereoscopes will accommodate this separation. However, most stereoscopes of the direct vision type, illustrated in figure 1, are usually satisfactory for the type of wedge shown*. The lenses of the stereoscope should be adjusted apart or together to fit the individual's eye spacing. This adjustment can be made by a simple but important test: Place a sheet of white paper on the table under the stereoscope. Then, while looking through the stereoscope, mark a dot with a pencil on the paper under the objective of the left eye and likewise mark a dot under the objective of the right eye that will appear in the same place as the first dot. The distance between these dots is measured on the paper. If this distance is 2.5 inches, then the lenses should be moved closer together and another check made. Such adjustments should be continued until the desired 2.0" spacing, determined by the width of the parallax wedge, is obtained.

The photos may now be separated to the 2" distance measured between the same images on each photograph. Care is necessary, in establishing the separation, to keep the conjugate principal points in a straight line. Photos should be firmly secured to the table with scotch tape or thumb tacks. After the stereoscopic pair of photos has been oriented and the lenses of the stereoscope are adjusted, the observer should have no trouble in seeing stereoscopically. But, he should be certain that an imaginary line passing through the center of the two lenses is parallel with the line of flight or the line drawn between the principal points.

Orientation and Reading of Parallax Wedge

The parallax wedge should be placed over the stereoscopic pair of photos so that the lines or dots either converge away from the observer or toward him. If converging away from the observer, as illustrated in figure 1, then the two lines will fuse under the stereoscope and each graduation farther away will appear to be higher. But, if the lines are converging toward him, then each fused graduation closer will appear to be higher. In general, it makes no difference which way the wedge is used but occasionally readings are easier because of the direction of ground slope or because of the direction of the calibrations on the wedge. After some practice an observer may become accustomed to using the wedge in one way and will not desire to make changes.

At first the observer should place the parallax wedge on the aerial photographs and approximately orient it without looking through the stereoscope. This is done by placing the left hand line on the left hand picture and

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* Theoretically, specialized parallax wedges could be designed to fit other types of stereoscopes.

the right hand line over the right hand picture. Each of the converging lines should pass approximately over the tree image observed, one on one photo, the other on its photo mate. Now the observer should look through the stereoscope. Near the selected tree he will see a single line with each graduation appearing to be higher or lower than the previous one. It will also be noted that the line appears to rise until a point where it appears to split into two diverging lines. Likewise, the line appears to descend to a point where it splits into two diverging lines. The single fused line is the portion of the wedge used. The wedge must be oriented with the marks on the left line opposite the corresponding marks on the right line.

After some study the observer will note that some of the graduations will appear to be about the same elevation as the tree top, while others will appear to be near the ground level. The parallax wedge should then be moved farther away or closer until the graduation on the sloping line that appears to be at ground level near to the base of the tree is located. The reading of the wedge at this point should then be recorded. Then, the parallax wedge should be moved until a graduation appears to be at the top of the tree. A second reading of the wedge is made at this point. The difference between these two readings is the parallax difference. On figure 2 this difference corresponds to the distance of ac + a'c'.

For even casual stereoscopic study the observer should be familiar with the procedures discussed here. Frequently precise orientation is not necessary, when brief stereoscopic examination is desired. However, if correct procedures are understood from past practice, an observer can approximate very closely the correct methods without actually going through the procedures step by step as given here

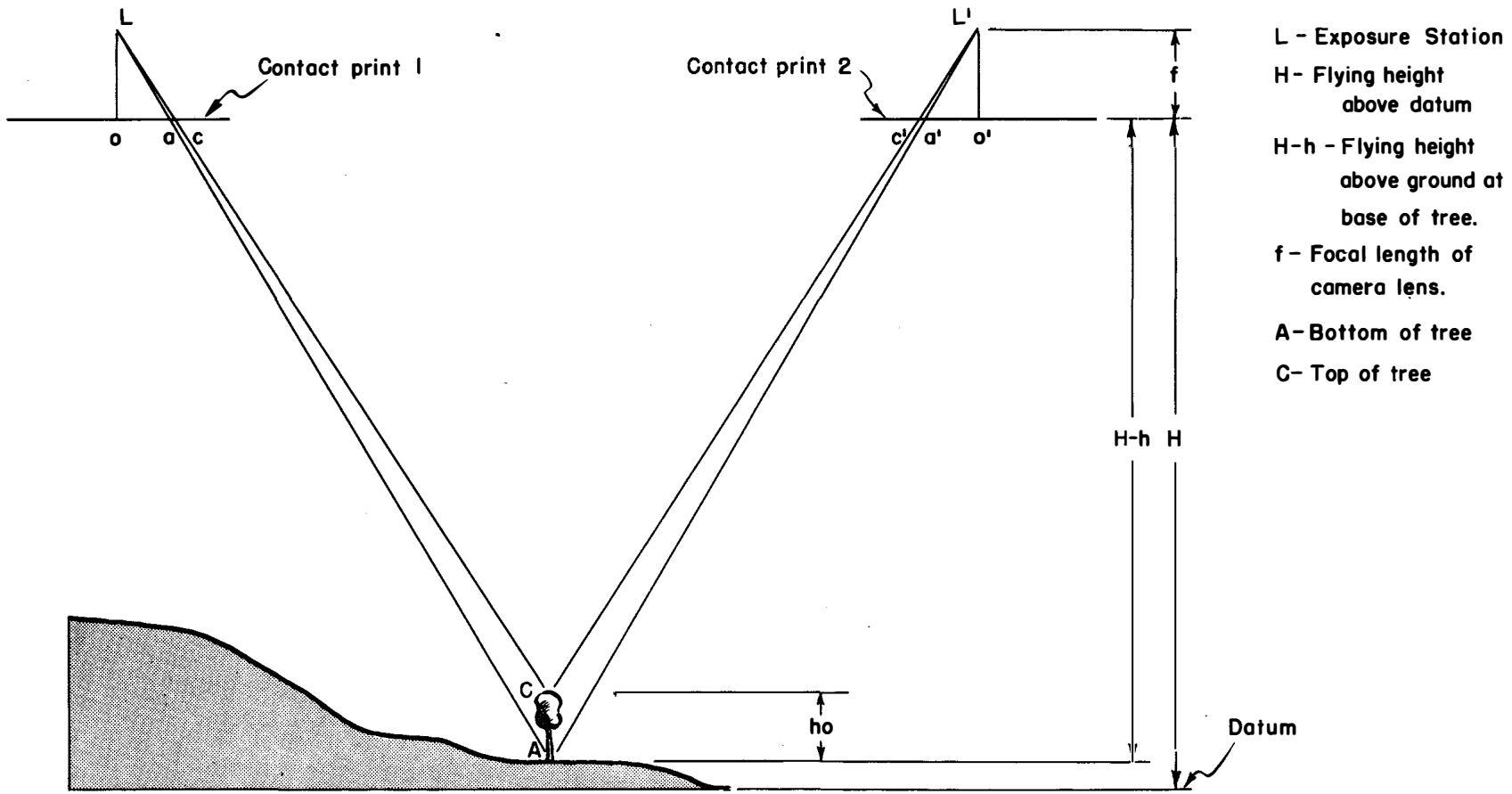
Converting Parallax Wedge Readings to Tree Height

Method I. A simple conversion is demonstrated below and is useful for many purposes:

1 Determine the approximate scale of aerial photographs as a representative fraction. This may be obtained from index mosaics, contact prints, or from the records of the photographic mission.

2 Parallax is the algebraic difference of the photographic distances to conjugate points as measured from the X-axis of aerial photographs parallel to the line of flight. Aerial photographs of level terrain have about the same parallax for all conjugate points. Therefore, the parallax for any one point is satisfactory, without loss of precision, for all conjugate points of a stereoscopic pair of aerial photographs. The points for easiest measurement of parallax are the principal points and their conjugates and may be obtained as follows: The photographic distance from the X-axis of photo #1 to its principal point is zero since the axis passes through the principal point. The photographic distance to the conjugate principal point is measured on photo #2 and is equivalent to $p_1p_2$ in figure 4. This

Figure 2.- ORIENTATION OF TWO VERTICAL AERIAL PHOTOGRAPHS SHOWING LOCATION OF TREE IMAGES ON EACH PHOTO



distance is measured with a ruler to the nearest 0.1 of an inch. As defined, the parallax of the principal point of photo #1 is the algebraic difference between zero and $p_1p_2$ or

$$p_1p_2 - 0 = p_1p_2$$

Therefore, the parallax of a principal point of photo #1 is measured on photo #2 and likewise the parallax of the principal point of photo #2 is measured on photo #1. Frequently, such parallaxes are called stereo-bases or photographic distances between exposure stations. But, less confusion is encountered if such distances are known as parallaxes.

Parallaxes of principal points when substituted to other conjugate points, if relief is present, will lead to errors in measuring tree heights. Such errors for some types of work may not be considered serious.

3. Next refer to figure 3 and locate the coordinate for the photo scale determined under point 1. Follow up this coordinate to the line which represents the parallax determined under point 2. Read the scale across to the left side of the chart. The reading represents the tree height per .001 of an inch in parallax difference. Other tree heights are in direct proportion to parallax differences obtained.

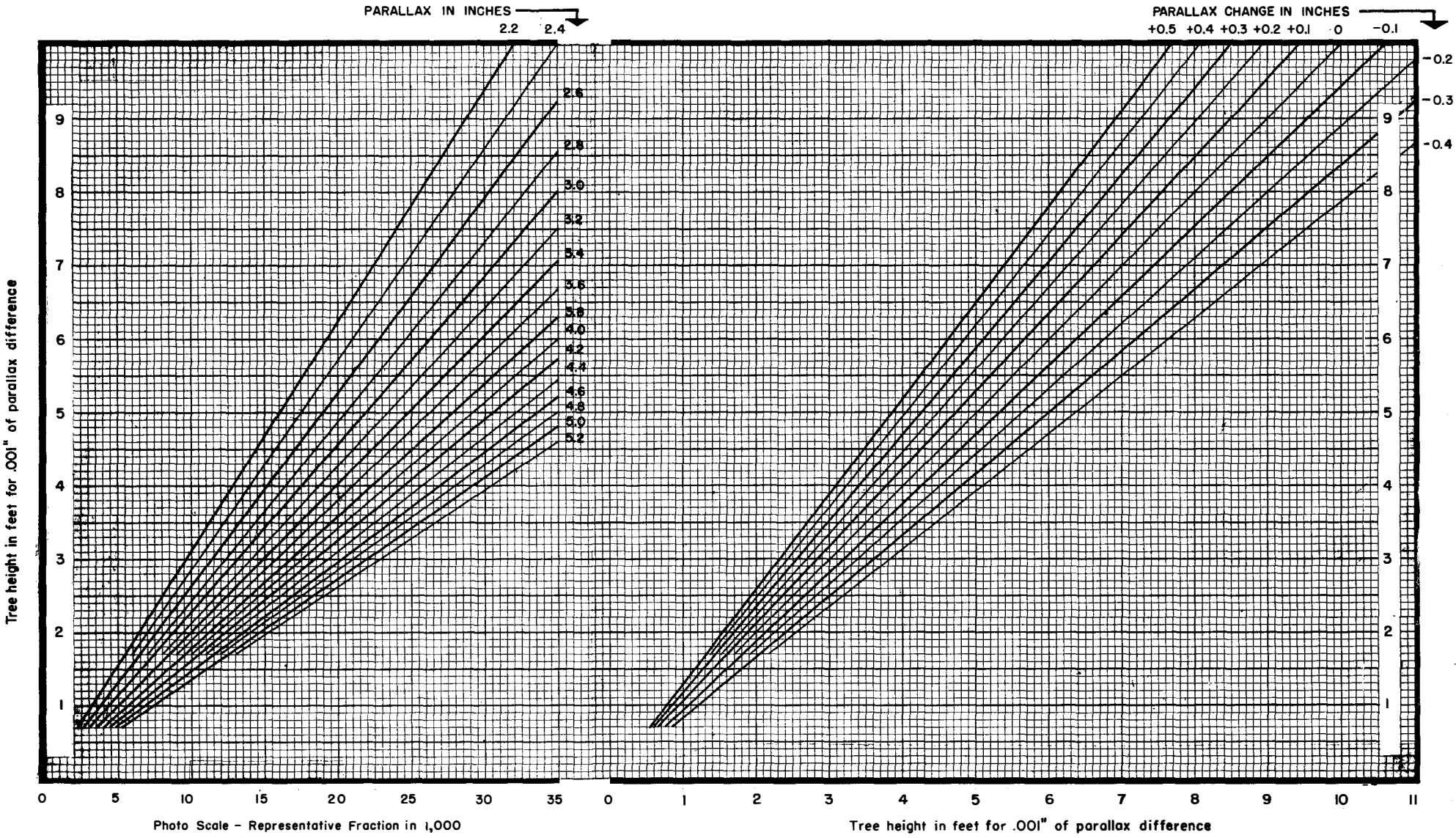
Example A. On a stereoscopic pair of aerial photographs a tree measured .018 inches in parallax difference. These pictures have an approximate scale of 1:20,000 and the parallax, or distance between principal point and conjugate principal point on the photo, measured 4.1". From figure 3 this photo scale and parallax indicate a 3.35' tree height for .001" of parallax difference. Therefore, this tree has a height of

$$ho = 18 \times 3.35 = 60.3 \text{ feet}$$

This method does not eliminate errors resulting from fluctuations in photo scale caused by topographic relief, flying height of the plane, or tilt. If the aerial photographs have tilt greater than 3 degrees from vertical, then the effect of this factor becomes serious. However, present flying practices usually keep the aerial photographs within this standard, and therefore, the effect of tilt is not considered further here. By this method a tree height can usually be measured within 10 feet 2 times out of 3, at photo scales of about 1:20,000. For some forest reconnaissance surveys an error of this magnitude is not serious. However, if greater precision is desired in estimating tree heights, the system described under Methods II or III is recommended.

Method II. Average parallax of principal points and average scale is calculated. This method is suggested for forest surveys where sample estimates are made from aerial photographs. Delineation of stand-size classes should not be made from this method. Method III is preferable.

**Figure 3.- TREE HEIGHT IN FEET BY PHOTO SCALE, PARALLAX AND PARALLAX CHANGE (Which includes the effect of scale change) FOR EACH .001" OF PARALLAX DIFFERENCE.**




FORMULA: $ho = \frac{f\,dP}{RF(P+dP)}$ where ho = Tree height in feet; RF = Scale, Representative Fraction; P = Parallax in inches; and dP = difference in parallax (assumed at .001"); f = focal length of camera lens in feet (assumed at .6875')

1. The average scale of the aerial photographs must be determined from the following formula:

$$R.F. = \left(\frac{d}{D} + \frac{d}{D} + \frac{d}{D} \text{ etc.}\right) \frac{n}{12} \quad \text{where}$$

R.F. = scale, representative fraction

D = ground distance between two points in feet

d = photo distance between same two points in inches

n = number of ground distances established for control lines

These control lines should be well distributed over the area having photo coverage. The ground distances may be determined from existing reliable maps such as U.S.G.S. quadrangles. The points at each end of the control lines must be identifiable on both the aerial photographs and maps so that comparable lines are used. About 15 control lines are recommended for this scale determination. Photo measurements should be made to the nearest one-hundredth of an inch.

2. The average parallax of principal points is determined from the following formula:

$$\text{Average } P = \frac{(P + P + P, \text{ etc.})}{n} \quad \text{where}$$

P = parallax, of principal points as explained under point 2, Method I

n = number of items

About ten distances between photo centers should be determined, drawn at random from the photo files for the area to be surveyed. The average of these ten items will give a reliable estimate of the average parallax. Measurements should be made to the nearest tenth of an inch.

3. Refer to figure 3 and estimate the height of a tree per .001 inch parallax difference using the average scale determined and the average parallax. Total tree height is directly proportional to the measured parallax difference.

Example B. An area of several hundred square miles is to have a timber survey. It is desirable to determine the average tree height from parallax measurements. Many of the forest stands have trees whose parallax difference measurement was .018 inches. There are 15 control lines well distributed, and 10 determinations of parallax of photos, or the distance between photo centers were made. Average scale is determined from the following measurements between control points made on photos and on a reliable map:

| d<br>Distance between control points on photos<br>Inches | D<br>Corresponding ground distance<br>Feet | $\frac{D}{d}$<br>Feet per inch |
|---|---|---|
| 2.24 | 3494 | 1560 |
| 3.69 | 6273 | 1700 |
| 4.24 | 6996 | 1650 |
| 5.04 | 8719 | 1730 |
| 3.41 | 5524 | 1620 |
| 2.24 | 3674 | 1640 |
| 3.62 | 6190 | 1710 |
| 5.05 | 8837 | 1750 |
| 4.62 | 7300 | 1580 |
| 4.09 | 6544 | 1600 |
| 6.01 | 9856 | 1640 |
| 4.14 | 6872 | 1660 |
| 2.03 | 3248 | 1600 |
| 3.05 | 4941 | 1620 |
| 4.15 | 6474 | 1560 |
| | Total feet/inch = | 24,620 |

R.F. (Representative fraction) = $\frac{15}{(12)(24,620)}$ = 1:19,696, or average photo scale

Assume that distance between centers of ten sample pairs of photos is measured in inches; then, using these measurements, average parallax is determined as:

$$\text{Average } P = \frac{3.7 + 3.9 + 4.1 + 3.7 + 3.8 + 3.6 + 3.5 + 4.0 + 4.1 + 4.2}{10}$$

$$= 3.86 \text{ inches}$$

From figure 3 this average scale and average parallax indicate a 3.45 foot tree height for each .001 inch of parallax difference. Therefore, the average height of trees with a .018 parallax difference is:

$$Ho = 18 \times 3.45 = 62.1 \text{ feet}$$

Within a specific survey area of several hundred square miles, the average height of those trees having a given parallax difference may be estimated within about 5 feet 2 times out of 3. This method should not be used for estimating height of specific trees or stands, particularly on areas of extreme relief. Under such conditions, errors up to 25 feet may be expected when using photos of 1:20,000 scale. If height of specific trees or stands are desired, Method III is suggested.

Method III.

1. Calculation of the photo scale

   (a) The approximate flying height above datum is calculated from a control line (see figure 4) and the ground elevations at each end of the line using the following formula derived from formula given by Church[3/]

$$(H) = \frac{Df(d_1 + d_2)}{2d_1d_2} + \frac{h_{G1} + h_{G2}}{2} \quad \text{where}$$

   (H) = approximate flying height above datum in feet

   D = ground distance between control points $G_1$ and $G_2$ in feet

   $d_1$ = photo distance between control points $G_1$ and $G_2$ to hundredths of an inch measured on photo #1

   $d_2$ = photo distance between control points $G_1$ and $G_2$ to hundredths of an inch measured on photo #2

   f = focal length of camera in inches

   $h_{G_1}$ = ground elevation in feet of point $G_1$

   $h_{G_2}$ = ground elevation in feet of point $G_2$

   (b) From the following formula photo scale is determined at the control point ($g_2$).

$$R.F. = \frac{f}{(H)-h} \quad \text{where}$$

   R.F. = scale; representative fraction

   (H) = approximate flying height in feet above datum calculated in 1(a)

   h = elevation of a control point in feet (point $G_2$)

   f = focal length of camera lens in feet (.6875)

2. The parallax is determined for control point $g_2$.

   (a) Carefully orient stereoscope and stereoscopic pairs of photos as suggested.

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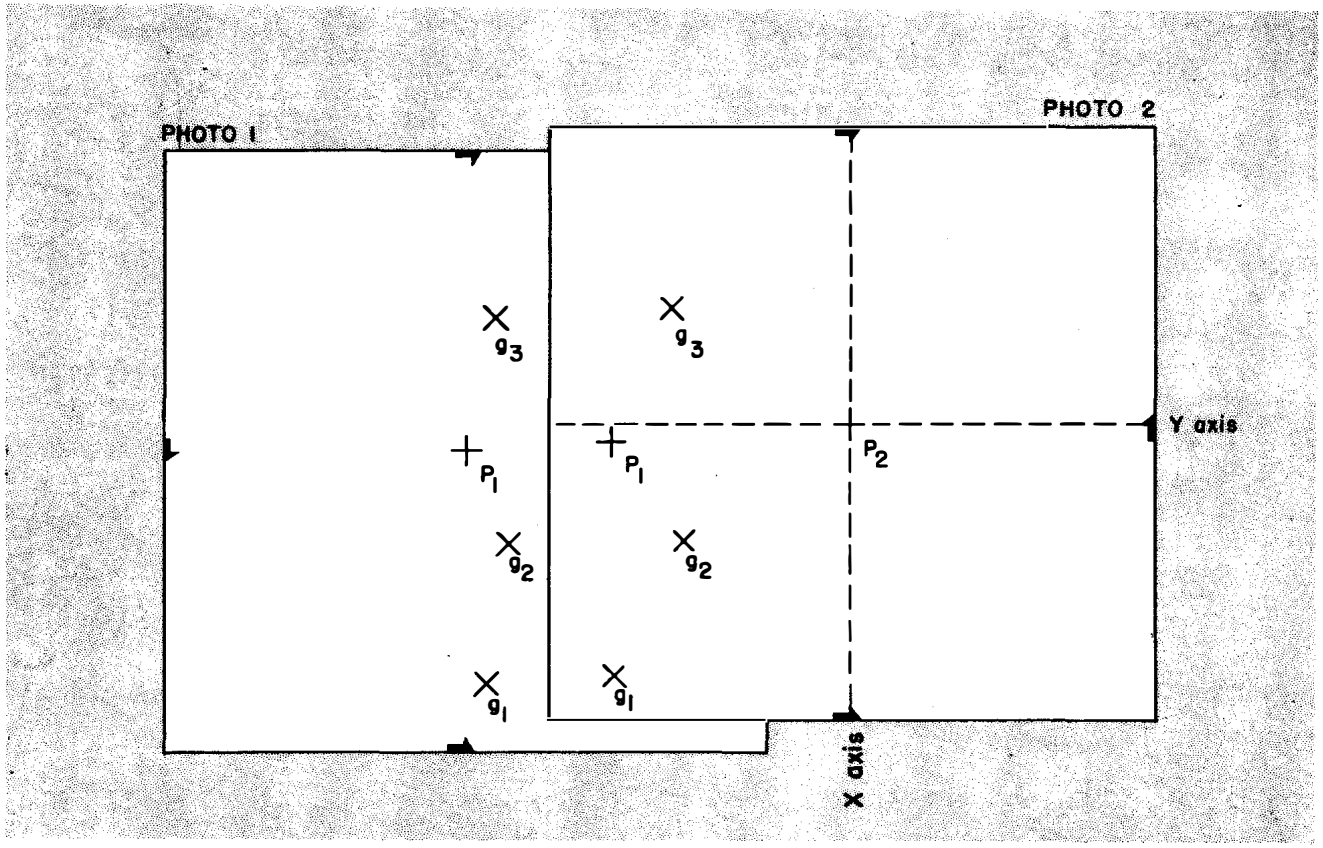
3/ Church, Earl F. Elements of Photogrammetry, Syracuse University Press, Syracuse, New York 1944.

Figure 4. - A LOCATION OF CONJUGATE POINTS ON A STEREOSCOPIC PAIR OF AERIAL PHOTOGRAPHS




## LEGEND

$P_1$ – Conjugate points for the principal point of photo 1.

$P_2$ – Principal point for photo 2.

$g_1, g_2$ – Represents conjugate points for control points.

$g_3$ – Represents conjugate points for an area of interest.

$P_1P_2$ – Parallax of point $P_1$.

(b) Measure the distance with a ruler from principal point to the conjugate principal point to the nearest 0.1 of an inch. This distance corresponds to $p_1p_2$ on photo 2, and is the parallax of $p_1$.

(c) Measure the distance between the conjugate points of the principal point to the nearest 0.1 of an inch. This is the distance between conjugate points $p_1$ in figure 4.

(d) Measure the distance between the conjugate control points for $g_2$. This is the distance between conjugate points of $g_2$ in figure 4.

(e) Add 2(b) to 2(c), then subtract 2(d), and and the result is the parallax of $g_2$.

3. An estimate of tree height at the control point ($g_2$) for each .001" of parallax difference may be read from figure 3 using the scale obtained under point (1) and the parallax obtained under 2.

4. If tree heights are desired at other locations, such as $g_3$ in figure 4, a correction may be necessary. This correction is not necessary in areas of moderate relief, but in areas of excessive relief the change in parallax must be considered. This change in parallax is found as follows. With a ruler, measure the distance between the conjugate points of the interested area ($g_3$ in figure 4). The difference between the value found in section 2(d) and that for point $g_3$ is the change of parallax. If the value under section 2(d) is larger, the change is plus and, likewise, if smaller, the change is minus.

5. Refer to figure 3 and locate the coordinate corresponding to the scale and parallax obtained for the control point ($g_2$). This coordinate is followed to the right, where parallax change is intercepted. The coordinate at this point is followed down and read. This value is the tree height in feet for each .001 of an inch of parallax difference at the point of interest. Other tree heights for areas of this same elevation are in direct proportion to the parallax difference between the bottom and top of trees as measured with the parallax wedge.

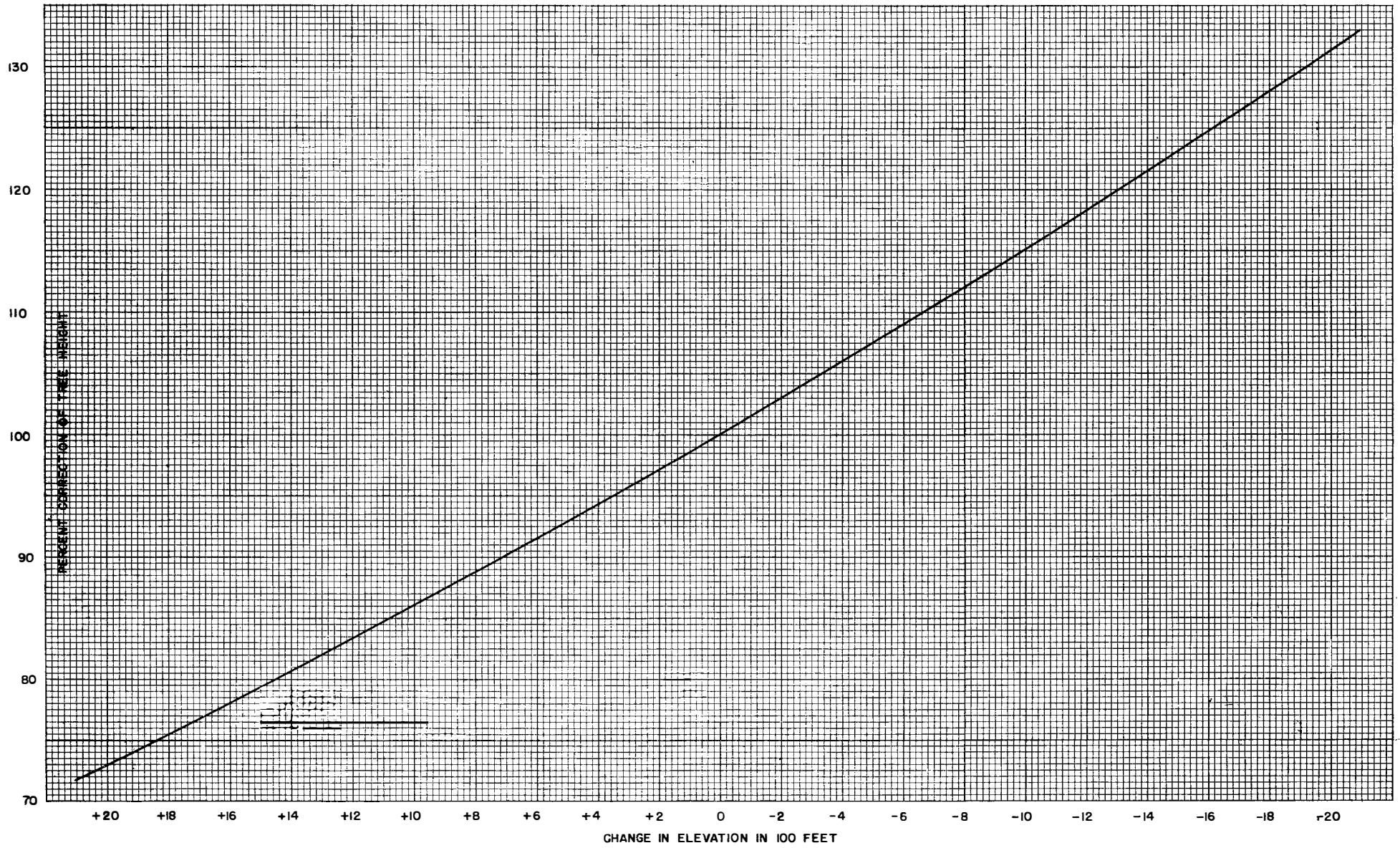
Example C. A pair of vertical photographs is taken with an aerial camera whose focal length is 8.25 inches. The ground distance of line $G_1G_2$ is 6626 feet and common to both photos. Point $G_1$ has a ground elevation of 943 feet and point $G_2$, 1169 feet. What is the height of trees with a parallax difference of .018 inches at point $G_3$?

1. The photo distance for $G_1G_2$ is measured on each photo and found to be:

$d_1$ = 4.31 inches

$d_2$ = 4.42 inches

Figure 5. – CORRECTION OF TREE HEIGHT FOR CHANGES IN GROUND ELEVATION ABOVE OR BELOW THE CONTROL POINT ELEVATION.



# POOR QUALITY

**The following pages are scanned at the best quality setting. The original pages are of poor quality and this is the best possible reproduction.**

2. The approximate flying height is:

$$(H) = \frac{Df(d_1 + d_2)}{2d_1d_2} + \frac{h_{G_1} + h_{G_2}}{2}$$

$$= \frac{(6626)(8.25)(8.73)}{38.10} + \frac{943 + 1169}{2} = 13,581 \text{ feet}$$

3. The scale at the control point is:

$$R.F. = \frac{.6875}{(H)-h_{G_2}} = \frac{.6875}{13,581 - 1,169} = \frac{.6875}{12,412} = 1:18,054$$

4. The parallax of control point $g_2$ is determined as explained under 2 of Method III.

$$P_{g_2} = p_1p_2 + p_1P_1 - g_2g_2 = 4.3 + 2.2 - 2.3 = 4.2$$

5. The parallax change between control point $g_2$ and area $g_3$ is:

$$g_2g_2 - g_3g_3 = 2.3 - 2.4 = 0.1$$

6. As shown in figure 3, this parallax change (-0.1 inches), along with the scale (1:18,054) and parallax (4.2 inches) of control point $g_2$ gives a tree height of 3.1 feet per .001 inch of parallax difference.

7. The height of trees whose parallax difference is .018 inches at point $G_3$ is:

$$Ho = 18 \times 3.1 = 55.8 \text{ feet}$$

Another method is useful for making the correction indicated under step 4, Method III, if reliable topographic maps are available. From such maps the difference in elevation between the control point and the point of interest is determined. By referring to figure 5 the percent correction of tree height may be determined for elevations either higher or lower than the elevation at the control point. In the example the parallax (4.2") at the control point and the photo scale (1:18,054) at this point give a tree height of 2.95 feet per .001" of parallax difference. The tree measured .018 parallax difference, which is 53.1 feet in total height. The difference in elevation between the control point and the location of the tree is minus 360 feet. This change is a percent correction of 105.2. Hence, the corrected height is 105.2% times 53.1, or 55.8 [illegible] which compares favorably with 55.8 calculated from the parall[illegible]

## Other Considerations

In practice the wedge should be used to measure trees whose base and top are readily visible on the photo. These measured trees serve as control by which height of other trees viewed under the stereoscope can be estimated ocularly, even though the ground beneath the canopy cannot be seen.

The three case studies presented above for converting parallax readings to tree heights were all based on the assumption that the focal length of the camera lens is 8.25 inches. For those focal lengths other than 8.25 inches the tree heights computed will vary in direct proportion to the changes of the focal length. For the example used in Method III, the tree height for .001" parallax difference is 2.95 feet for 8.25" lens. If a 6.25" lens were used, then the tree height would be:

$$Ho = \frac{(2.95)(6.25)}{8.25} = 2.2 \text{ feet}$$

## Design of Parallax Wedge

The parallax wedges have various designs. The marks may consist of lines, dots, or circles in various colors. Rows of dots proved effective in open areas, but it was difficult to get tree height measurements in dense forests. The black color of the dots would blend with the photo colors, hence making readings difficult. Also, it was inaccurate to read the parallax on the ground in small forest openings because the dots would not fuse. Further, some annoyance was observed when the dots would literally jump when the wedge was rotated.

The substitution of a red line for black dots improves one's ability to read the wedge at the ground in small openings in the forest canopy. Under the stereoscope two lines fuse and appear to cut through the forest to those ground areas which are visible through small openings of the forest. The red color of the line furnishes good contrast to the photographic shades, thus greatly improving its visibility.

## Summary

A new and desirable device, the parallax wedge, has been recently introduced for measuring the total height of trees on vertical aerial photographs. Some helpful hints are suggested in the use of this instrument to enable the forester to become more familiar with its application. Three methods are outlined for converting the parallax wedge readings to tree heights in feet with an estimate of the possible errors involved in each case.

[redacted]he false impression that a great amount of work is [redacted]nts. Actually initial tree heights under [redacted]5 minutes, including all steps. Other [redacted]of a few seconds. Methods II or III

2. The approximate flying height is:

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## Design of Parallax Wedge

The parallax wedges have various designs. The marks may consist of lines, dots, or circles in various colors. Rows of dots proved effective in open areas, but it was difficult to get tree height measurements in dense forests. The black color of the dots would blend with the photo colors, hence making readings difficult. Also, it was inaccurate to read the parallax on the ground in small forest openings because the dots would not fuse. Further, some annoyance was observed when the dots would literally jump when the wedge was rotated.

The substitution of a red line for black dots improves one's ability to read the wedge at the ground in small openings in the forest canopy. Under the stereoscope two lines fuse and appear to cut through the forest to those ground areas which are visible through small openings of the forest. The red color of the line furnishes good contrast to the photographic shades, thus greatly improving its visibility.

## Summary

A new and desirable device, the parallax wedge, has been recently introduced for measuring the total height of trees on vertical aerial photographs. Some helpful hints are suggested in the use of this instrument to enable the forester to become more familiar with its application. Three methods are outlined for converting the parallax wedge readings to tree heights in feet with an estimate of the possible errors involved in each case.

[redacted] the false impression that a great amount of work is [redacted]nts. Actually initial tree heights under [redacted]5 minutes, including all steps. Other [redacted] of a few seconds. Methods II or III

require about one-half hour, but they furnish the basic data which may be used over 1,000 to 15,000 acres or more. We have found the parallax wedge to be a valuable tool in photo interpretation and through its use the ground work necessary for forest surveys may be reduced with a corresponding reduction of costs, or greater detail may be obtained at comparable cost.

Extensive controlled test data are not yet available to demonstrate precisely the range in accuracy of this instrument under a wide variety of conditions. However, our experience over the past year indicates that in northeastern forests the instrument will meet the general standards which have been mentioned. Further studies are needed to determine more accurately the advantages and limitations of this instrument, both under ideal and practical working conditions. It is hoped that this paper will inspire foresters to test thoroughly the applicability of the parallax wedge to their own problems of forest survey and to report the results.